Information Circular 9448

Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design

Edited by Christopher Mark, Ph.D., Keith A. Heasley, Ph.D., Anthony T. Iannacchione, Ph.D., and Robert J. Tuchman

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
Pittsburgh, PA

June 1999

International Standard Serial Number
ISSN 1066-5552

CONTENTS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot (feet)	kPa/m	kilopascal per meter
GPa	gigapascal	m	meter
ha	hectare	mm	millimeter
hr	hour	MN/m	meganewton per meter
in	inch	MN/m^3	meganewton per cubic meter
in/in	inch per inch	MPa	megapascal
kg/cm^2	kilogram per square centimeter	psi	pound (force) per square inch
kg/m^3	kilogram per cubic meter	psi/ft	pound (force) per square inch per foot
km	kilometer	sec	second
km^2	square kilometer	%	percent
kN/m^3	kilonewton per cubic meter	°	degree

PROCEEDINGS OF THE SECOND INTERNATIONAL WORKSHOP ON COAL PILLAR MECHANICS AND DESIGN

Edited by Christopher Mark, Ph.D.,[1] Keith A. Heasley, Ph.D.,[1]
Anthony T. Iannacchione, Ph.D.,[2] and Robert J. Tuchman[3]

ABSTRACT

Pillar design is the first line of defense against rock falls—the greatest single safety hazard faced by underground coal miners in the United States and abroad. To help advance the state of the art in this fundamental mining science, the National Institute for Occupational Safety and Health organized the Second International Workshop on Coal Pillar Mechanics and Design. The workshop was held in Vail, CO, on June 6, 1999, in association with the 37th U.S. Rock Mechanics Symposium. The proceedings include 15 papers from leading ground control specialists in the United States, Canada, Australia, the United Kingdom, and the Republic of South Africa. The papers address the entire range of issues associated with coal pillars and have a decidedly practical flavor. Topics include numerical modeling, empirical design formulas based on case histories, field measurements, and postfailure mechanics.

---

[1]Supervisory physical scientist.
[2]Deputy director.
[3]Technical writer-editor.
Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

INTRODUCTION

By Christopher Mark, Ph.D.[1]

Pillar design is one of the oldest and most fundamental of the mining sciences. Without pillars to support the great weight of the overburden, underground coal mining would be practically impossible. Coal pillars are employed in a wide variety of mining operations, from shallow room-and-pillar mines to deep longwall mines. Yet despite more than 100 years of research and experience, pillar failures continue to occur, placing miners' lives at risk. Some recent examples are [Mark et al. 1998]:

Massive collapses: In 1992, miners were splitting pillars at a mine in southern West Virginia when the fenders in a 2.3-ha area suddenly collapsed. The miners were knocked to floor by the resulting airblast; 103 ventilation stoppings were destroyed. At least 12 similar events have occurred in recent years in the United States and 15 others in Australia, fortuitously without a fatality.

Pillar squeezes: At a coal mine in Kentucky, pillars were being extracted in the main entries under 270 m of cover. The pillars began to crush in response to the vertical load, resulting in a roof fall that killed two miners. This incident is an extreme example of hazardous conditions that can be associated with slow pillar failure. At least 45 recent instances of pillar squeezes in room-and-pillar mines have been identified.

Longwall tailgate blockages: In 1984, 26 miners at the Wilberg Mine in Utah could not escape a deadly fire because of a tailgate roof fall. Similar blockages were common in the 1980s, and 50 cases have been documented.

Pillar bumps: Extracting the initial lift from a standing pillar at a deep operation in eastern Kentucky resulted in a bump that killed two miners. However, bumps are not confined to pillars; another fatal bump occurred at a longwall face in Utah just days later.

Multiple-seam interactions: Some studies indicate that most remaining coal reserves will experience multiple-seam interactions. At a mine in West Virginia where four seams had been previously extracted, one fatality occurred when the roof collapsed without warning beneath a remnant barrier pillar.

Abandoned mine subsidence: As suburban development expands into historic coal mining areas, unplanned subsidence has become an important issue. In one case, residents above 50-year-old workings were disturbed by seismicity emanating from collapsing pillars. In the Republic of South Africa, collapsing pillars in the Vaal Basin are creating large sinkholes that threaten many homes.

To help reduce the safety hazards of pillar failures, this *Second International Workshop on Coal Pillar Mechanics and Design* was organized. (The first workshop was held in Santa Fe, NM, in 1992.) The proceedings of the second workshop feature 15 invited papers from leading rock mechanics experts in the United States, Australia, the Republic of South Africa, the United Kingdom, and Canada. Mines in these five countries employ increasingly similar methods, including:

- Retreat longwall mining, usually using large chain pillars;
- Room-and-pillar mining with continuous mining machines; and
- Roof bolts for primary roof support.

The similarity of mining methods means that it is easier and more valuable to transfer safety technologies like pillar design from one country to another. Indeed, one of the striking features of these proceedings is the convergence of research results across international borders.

Other trends affecting the mining industries of the five countries are also reflected in these proceedings, some of which have been less positive. In the 7 years since the first workshop, underground production has risen in Australia and the Republic of South Africa, declined in the United Kingdom and Canada, and remained steady in the United States. However, great employment losses have occurred in all five countries because of technological advances and dramatic productivity increases.

One consequence has been a significant decline in institutional support for mining research. Since 1992, the U.S. Bureau of Mines (USBM), the Canada Centre for Mineral and Energy Technology's (CANMET) Coal Research Laboratory, British Coal's Headquarters Technical Division, and the South African Chamber of Mines research department have all closed their doors. Government funding for mining research is now indirect and open for competition everywhere, except in the United States. In the United States, the National Institute for Occupational Safety and Health (NIOSH) has taken up the USBM's traditional mine safety research role, although at a reduced level, and continues to receive direct funding from the U.S. Congress.

University mining departments have also been under pressure due to fluctuating student enrollments, reduced research funding, and a shortage of qualified junior faculty. Lower profit margins and a renewed emphasis on the bottom line has meant that few mining companies now maintain any in-house research capability. As the traditional sources of mining research have faltered, in many cases private consulting firms have taken up the challenge. Often staffed by former government researchers and sometimes supported in part by government contracts, consultants are now often on the cutting edge of research.

[1]Supervisory physical scientist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

In comparing the proceedings of the second workshop with those of the first [Iannacchione et al. 1992], the most obvious difference is that the current collection of papers is a slimmer volume. There are 15 papers in these proceedings, compared with 23 in 1992. Australia, which in many ways has the healthiest mining research community, is the only country to see its representation increase (see table 1). Although the number of papers from industry, government, and academia all decreased by at least 50%, the number of papers from private consultants more than doubled.

Another consequence of the changed research environment is reflected in the proceedings' pervasive emphasis on practical problem-solving. Although about one-half of the papers at the first workshop addressed issues of a more theoretical nature, nearly every paper in the current collection uses case histories, field measurements, and/or practical experience to develop techniques for solving real-world pillar design problems.

The papers divide almost evenly between those that focus primarily on the application of numerical modeling and those that discuss empirical formulas derived from statistical analysis of case histories (table 1). Of the numerical modelers, two used finite-difference methods (Gale, Cassie et al.), four used boundary elements (Heasley-Chekan, Maleki et al., Zipf, Karabin-Evanto), and one used finite elements (Su-Hasenfus). Field measurements feature prominently in six papers, with Cassie et al., Colwell et al., and Gale monitoring stress and deformation, Heasley-Chekan and Karabin-Evanto mapping underground conditions, and Biswas et al. measuring changes in rock strength.

In general, however, the similarities between the papers are more striking than their dissimilarities despite the variety of countries, author affiliations, and research methods. For example, new empirical formulas are presented for the Republic of South Africa (van der Merwe), the United States (Mark), and Australia (Galvin et al.). Derived independently from different sets of case histories from around the world, the three formulas are within 15% of each other (see figure 1).

Five papers (Su-Hasenfus, Gale, Cassie et al., Mark, and Colwell et al.) explicitly address the design of squat (large width-to-height (w/h) ratio) pillars, primarily for protection of longwall gate entries. All agree that the strength of these pillars can vary widely depending on the roof, floor, and seam parting characteristics. Moreover, the strength of the roof is often just as important to the design process as the strength of the pillar itself. The degree of consensus that has been achieved on this complex topic is an important advance. At the other end of the w/h scale, van der Merwe, Zipf, and Mark address slender pillars and their potential for sudden collapse. Again, all three reach similar conclusions regarding the importance of pillar geometry and postfailure pillar stiffness.

The beginnings of a consensus are also evident in one of the oldest pillar design controversies—the value of compressive strength tests on coal specimens. Only two papers (Karabin-Evanto and Maleki et al.) make use of laboratory tests to evaluate seam strength. On the other hand, van der Merwe, Su-Hasenfus, Cassie et al., Galvin et al., Gale, and Mark all conclude that variations in the uniaxial compressive strength have little effect on the in situ pillar strength.

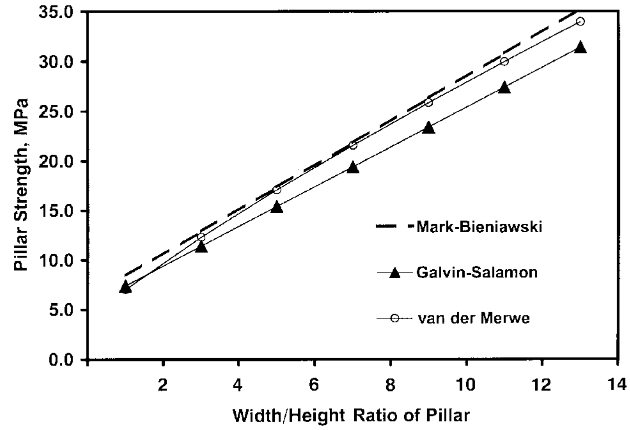

Figure 1.—Empirical pillar strength formulas derived from case histories by Mark (U.S.A.), Galvin (Australia), and van der Merwe (Republic of South Africa).

With the focus on pillar strength, it is important not to overlook the other half of the design equation—the load. Gale and Colwell et al. describe field measurements that shed new light on the loads that occur during longwall mining. Heasley-Chekan and van der Merwe address the effect of overburden behavior on the pillar loading. Kramer et al. have extended their fracture mechanics approach for estimating load distribution to consider the effects of other kinds of supports.

Other special topics that are discussed in these proceedings include the effect of weathering on long-term pillar strength (Biswas et al.), the geologic and geotechnical factors that affect the potential for coal bumps (Maleki et al.), thick-seam room-and-pillar mining (Cain), multiple-seam mine design (Heasley-Chekan), and the strength of rectangular pillars (Galvin et al. and Mark).

One final comparison between the first and second workshops is perhaps in order. The proceedings of the first workshop [Iannacchione et al. 1992] included papers from a number of now retired individuals whose names have been synonymous with pillar design for nearly 3 decades: Salamon, Bieniawski, Wagner, Barron, and Carr. In many ways, their contributions laid the foundation upon which rests much of our current understanding of coal pillars. Their retirement has left a large gap that cannot be filled (although it is hoped that they will continue to contribute to the profession!). To paraphrase Sir Isaac Newton, it is only by standing on the shoulders of such giants that we can hope to achieve further progress.

Table 1.—Summary of papers for the Second International Workshop on Coal Pillar Mechanics and Design

Primary author	Country	Affiliation	Method
Biswas	Australia	University	Empirical.
Cain	Canada	Mining company . .	Empirical.
Cassie	U.K.	Consultant	Numerical.
Colwell	Australia	Consultant	Empirical.
Gale	Australia	Consultant	Numerical.
Galvin	Australia	University	Empirical.
Heasley	U.S.A.	Government	Numerical.
Karabin	U.S.A.	Government	Numerical.
Kramer	U.S.A.	Government	Numerical.
Maleki	U.S.A.	Consultant	Empirical/numerical.
Mark	U.S.A.	Government	Empirical.
Su	U.S.A.	Mining company . .	Numerical.
van der Merwe .	South Africa .	Consultant	Empirical.
Zipf	U.S.A.	University	Numerical.

REFERENCES

Iannacchione AT, Mark C, Repsher RC, Tuchman RJ, Jones CC, eds. [1992]. Proceedings of the Workshop on Coal Pillar Mechanics and Design. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9315.

Mark C, Su D, Heasley KA [1998]. Recent developments in coal pillar design in the United States. In: Aziz NI, Indraratna B, eds. Proceedings of the International Conference on Geomechanics/Ground Control in Mining and Underground Construction. Wollongong, New South Wales, Australia: University of Wollongong, Vol. 2, pp. 309-324.